Dec. 2, 1969 K. L. HUJSAK 3,481,399

RECOVERY OF OIL BY FLASHING OF HEATED CONNATE WATER

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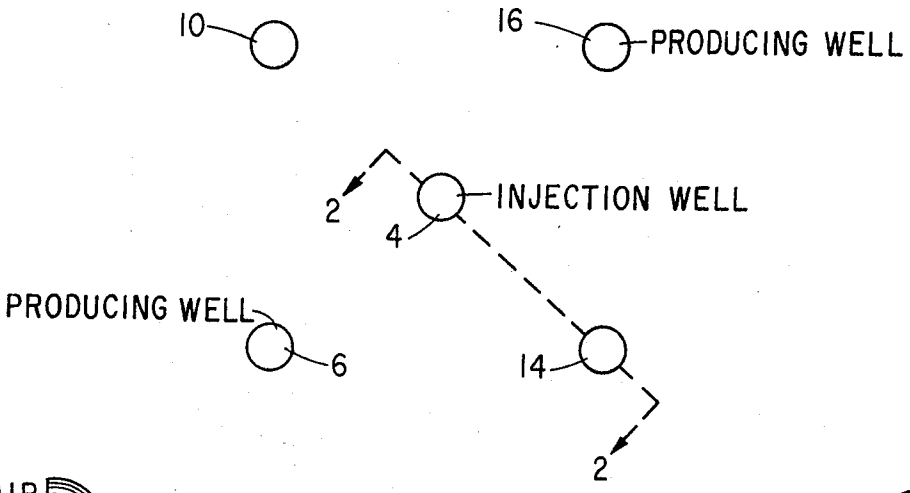


FIG. 1

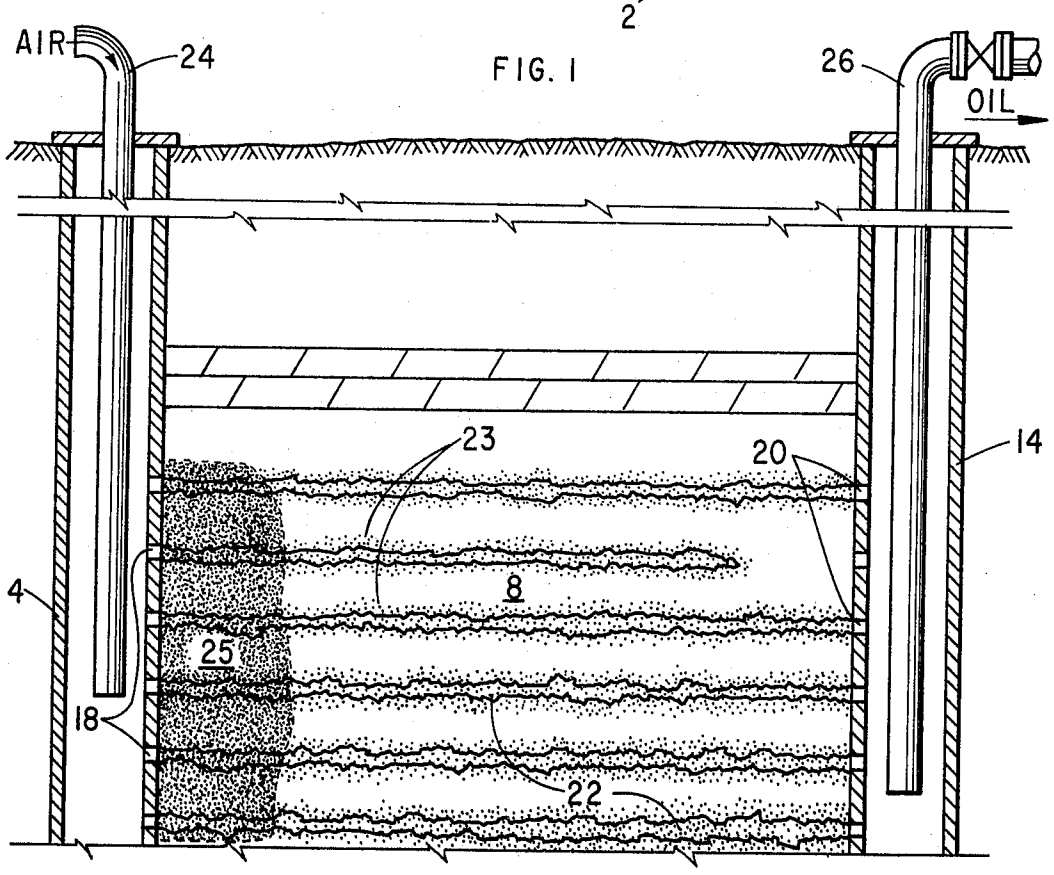


FIG. 2

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RECOVERY OF OIL BY FLASHING OF HEATED CONNATE WATER

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U.S. Cl. 166—251 8 Claims

ABSTRACT OF THE DISCLOSURE

In the production of fluid hydrocarbons from unconsolidated heavy oil or tar sand deposits, the formation is fractured between injection and producing wells after which it is ignited at the approximate level of the fractures. The resulting combustion front is moved toward the producing well by injection of air at pressures sufficient to hold the fractures open. When a temperature increase is observed at the producing well the latter is shut in while air injection is continued until the desired formation heating is accomplished. During this heating period connate water is heated to an average temperature in excess of 200° F. The producing well(s) is opened, the hot water in the reservoir flashes into steam, thereby driving the oil of reduced viscosity to the producing well.

INTRODUCTION

The present invention relates to the thermal recovery of petroleum from underground deposits thereof. More particularly, it is concerned with the production of liquid petroleum, preferably heavy oils and/or tars, from deposits thereof wherein water in the deposit is heated under pressure and thereafter flashed into steam. The latter serves as the prime driving force behind the heated oil or tar, causing it to flow into the open producing well.

BACKGROUND OF THE INVENTION

Production of heavy oil or tars by the use of heat, particularly in the form of steam, has been practiced for some time. Single well steam injection followed by a depressuring step accompanied by production has been widely used as a means for producing the heavier oils from relatively shallow thick formations. This procedure is frequently referred to as the cyclic or "huff and puff" method. While it is possible to recover additional oil from such deposits by this procedure, it has not met with unqualified success—one of the principal drawbacks being that it does not supply the reservoir with sufficient energy to move the oil toward the producing well in the quantities it should. This process is generally used in reservoirs having little or no energy and hence, any oil moving to the producing well largely depends for its energy on that furnished by flash vaporization of hot condensate back in the formation when the producing well is depressurized and placed on production.

Forward combustion, of course, is a technique that has been known for many years but up to the time of the present invention—insofar as I am aware—has been considered to be limited to reservoirs containing oils having an API gravity of from about 20° to 40°. It has been the common conception that forward combustion could not be effected in reservoirs containing heavy viscous oils and the like because the cold reservoir rock yielding the oil lies just ahead of the combustion zone. At the combustion zone the viscosity of the oil is at a minimum. However, as the pressure of the system forces the oil toward the producing well, the oil decreases in temperature to that of the unburned portion of the reservoir. Eventually, it was thought, resistance to flow would be so great that combustion could no longer continue because it would be impossible to supply air at a satisfactory rate to sustain combustion. Under the conditions of forward combustion previously used, the foregoing appraisal of the process is probably accurate.

In Hujsak et al. U.S. 3,384,172, a method for producing heavy oils and/or tars is described in which a combustion zone is first formed in an injection well penetrating, for example, a formation containing a heavy crude oil. After a burning zone has been established, air or the equivalent is introduced into the formation via the ignited injection well under a pressure sufficient to lift the overburden or fracture the formation. Before, after, or during this operation, steam injection in an offset producing well is started. Generally this steam is wet or low grade and may be at a pressure of from about 500 to 1500 p.s.i. and at a temperature of from about 470° to 600° F. Ordinarily, after the combustion step has been carried out long enough to establish a good heat bank, the flow of air into the injection well is suspended while steam is introduced into the formation via the producing well. During this latter step the injection well is preferably shut in and inert gaseous combustion products remain in the formation. After the steam injection step is completed, which may extend from one to several weeks, the producing well is depressured thus allowing the pressure in the entire system to be decreased. At this time, oil of substantially reduced viscosity in the vicinity of the producing well is forced toward the latter not only as a result of the pressure generated by revaporization of condensate back in the formation when the producing well is opened, but by the accumulated mass of hot inert gaseous combustion products from the forward burning step. This treatment conditions the reservoir for application of conventional secondary recovery methods, such as ordinary (low pressure) forward combustion, combustion involving air and water injection, various flooding techniques, and the like.

In a variation of the above procedure, the formation may be fractured prior to establishment of a combustion front in the injection well. The fracturing operation may be carried out in accordance with known methods employing as fracturing fluids materials such as water, air, or special fluids with or without propping agents. While fractures are created in consolidated formations, it is not known what happens when petroleum deposits in unconsolidated formations, such as tar sands, are subjected to fracturing conditions. It is known, however, that zones or channels of higher permeability exist throughout the formation between injection and producing wells after the formation has been subjected to fracturing conditions than existed prior to such treatment. These fractures are preferably placed at a number of different levels and when they have been produced, as is frequently evidenced by a sharp drop in injection pressure, the face of the formation adjacent the injection well is ignited. To sustain the resulting combustion front and drive it out into the formation for a distance sufficient to raise the average temperature thereof to a level in excess of about 200° F., relatively high surface air injection pressures are employed. In general, it may be said that the pressure required at this point in our process is that necessary to keep the front moving out into the reservoir. For example, in tar sands at a depth of about 1000 feet, such pressure will frequently be found to range from about 1100 to 1200 p.s.i.

Combustion at these high pressures occurs primarily in the fractures or zones of increased permeability and is continued until a temperature increase is observed either in a producing well or in an observation well in close proximity to such producing well. In either case the temperature will be observed to increase from the normal formation temperature up to temperatures of 500° to

800° F. in a matter of several weeks or months after the initial increase is recorded. The time within which such temperature increase is observed, of course, depends on many factors such as, for example, the nature of the formation, distance between injection and producing wells, the permeability created by the combined fracturing and forced forward burning steps, etc. However, with wells only a few hundred or so feet apart, a period of several months may be required before heat breakthrough is noticed.

DESCRIPTION OF THE INVENTION

I have now discovered that petroleum, particularly heavy oils and tars, can be readily produced without steam treating the production wells and without application of a secondary recovery method following combustion. Briefly, the process of my invention comprises first forming a combustion zone in an injection well penetrating, for example, an unconsolidated formation containing heavy crude oil. Once a combustion zone has been established—as may be done in accordance with either of the procedures described and claimed in U.S. 3,223,165 or U.S. 3,244,231—a forced high pressure forward combustion process is initiated. This heating step is accomplished merely by injecting air at pressures sufficient to lift the overburden after a combustion front has been established. Under such conditions zones or channels of high permeability are formed causing the combustion process to occur primarily in these locations. After burning is effected in this manner for a time, e.g., several months, air injection may be discontinued and the heat thus generated allowed to diffuse throughout the oil bearing formation, while the producing wells are shut in. The object is to heat as much of the oil as possible to a temperature in excess of 200° F.

Assuming, for example, a well pattern employing at least one injection well and several surrounding producing wells, each producing well is shut in when the aforesaid temperature increase is first observed in or near such well. Owing to variations in permeability, etc., the combustion zone or heating bank does not normally reach all producing wells at the same time. After the temperature rise is seen in the last of the several producing wells and the latter is shut in, operations are discontinued for a period of six weeks to two months or even longer to permit the burned out zones to be resaturated with oil. During this period the heat diffuses out into the reservoir causing at least a major portion of the oil to increase to an average temperature in excess of 200° F. at pressures that typically may range from about 1000 to 1500 p.s.i. During this time the connate water is heated to a temperature well above its boiling point at atmospheric pressure. Likewise, the oil has changed in viscosity from about 1 to 2 million centipoises to about 300 centipoises at 55° F. On opening the producing wells the decrease in pressure causes the hot connate water to flash into steam which in turn serves as an ideal driving agent for the oil of reduced viscosity directing it to the low pressure sink around the producing wells. At the end of one such heating and depressuring cycle, the remaining oil is associated with most of its original connate water. The cycle of raising the pressure by injecting additional air and then depressuring again may be employed to recover more oil. In some cases it may be desirable to add water with the air for second and subsequent cycles.

The above described procedure, in a relatively uncomplicated and efficient manner, serves to recover a major portion of the heavy oil or tar in place. This method was discovered by accident when the above described process was followed up to the pressure reduction or "blow-down" step. At that time a five spot pattern was employed using a central injection well and four producing wells. An influx of sand was discovered in two of the producing wells and it was necessary to stop the operation and repair them. To accomplish the repair it

was necessary to reduce the pressure within the formation by opening up the other two producing wells. The pressure was lowered from about 1000 p.s.i. to about 90 p.s.i. over a period of 6½ months. During this blow-down step 29,000 barrels of fluid were produced of which 12,600 barrels were dry oil. The oil recovered amounted to 14% of all the oil within the well pattern which was situated on about ½ acre and to about 22% of the oil heated to 150° F. or higher. Oil production was still at a rate of 35 barrels per day when production was discontinued.

In the accompanying drawings, FIGURE 1 is a diagrammatic plan view of a typical well pattern which may be used in the recovery of heavy oils or tars in accordance with the process of my invention.

FIGURE 2 is a sectional view of a segment taken along line **2—2** of the pattern shown in FIGURE 1.

DESCRIPTION OF A PREFERRED EMBODIMENT

The method of my invention may be further illustrated by reference to the accompanying drawings in which cased wells **4** and **14**, respectively, penetrate a heavy oil bearing unconsolidated formation **8** at a depth of about 1100 feet. The thickness of formation **8** was 120 feet and the area enclosed by the well pattern shown in FIGURE 1 was approximately ½ acre. After forming perforations **18** and **20** in the injection well and producing well, respectively, formation **8** was subjected to treatment with water at a surface pressure of about 750 p.s.i.g. in accordance with currently accepted techniques to create fractures or zones of increased permeability **22**, placing wells **4, 6, 10, 14** and **16** in communication with one another—at least when a fluid under high pressure is forced into said zones.

After the fracturing step, formation **8** was ignited through perforations **18** in injection well **4** by means of a catalytical igniter employing a methanol-air mixture. Good ignition was effected by injection of 7 million B.t.u., based on the quantity of methanol (119 gallons) consumed. The ignition required about 34 hours with approximately 3.6 gallons of alcohol and 15,000 standard cubic feet of air being used per hour. Air injection pressure ranged from about 300 to 1800 p.s.i.g. However, most of the time it remained at 500 to 800 p.s.i.g.

When ignition was established the igniter was removed from well **4** and air injection was begun through pipe **24** at an initial rate of 300M s.c.f.d., ultimately increasing to 900M s.c.f.d. Air injection was started at 600 p.s.i.g. and increased during the forced forward combustion phase of the process to above 1100 p.s.i.g. The increasing pressure trend was interrupted by many small decreases in pressure, several being around 50 p.s.i.g. and one relatively large decrease of about 150 p.s.i.g., from 1000 to 845 p.s.i.g. Apparently the pressure decreases were the result of fracturing within the formation that extended the existing flow channels or created new ones.

Gas production through pipe **26** increased in well **14** to about 100M s.c.f.d. about four days after the start of forward combustion (after the ignition step). Then about 10 days later a temperature response—a 5° F. increase—was observed in this well at 1055 to 1085 feet after which it was shut in. Thereafter the downhole temperature increased to slightly above 400° F. over a period of about 9½ months. Under the conditions of operation, the principal burning occurred in fractures **22** forming a burned zone **23**. As operations, progressed a partially burned or high temperature zone **25** was formed. At 1085–1090 feet well **10** had a temperature increase of 15° F. about six weeks after combustion began and was then shut in. Approximately two months later a temperature of 840° F. was reached at this depth and a total of 377 barrels of water was injected continuously into well **10** over a period of two weeks to maintain the well temperature below 500° F. Over a similar time interval no temperature responses were noticed in wells **6** and **16** in-

dicating a directional permeability trend. However, heat breakthrough was observed in wells 2 and 4 within about 4 months and 7 months, respectively, after combustion was initiated. Each of the wells was shut in when a temperature rise was noticed. Thereafter the entire system remained closed for a period of six weeks to permit the heat to distribute more evenly throughout the well pattern and to allow the burned out stringer and gas flow channels in the tar sand to resaturate with tar. At the end of the six week heat soaking period the system pressure was about 900 p.s.i.g. and the tar sand temperature in the test pattern averaged about 285° F. Wells 10 and 14 were then opened and oil produced through small chokes. These wells produced flowing at the rate of 70–80 BOPD (dry basis) for about four months. Later they were put on pumps and over the test period produced a total of 8,300 barrels of oil. At the end of the producing period, i.e., about 6½ months, the formation pressure was 90 p.s.i.g. Total oil production (dry basis) from all four wells during this time was 12,600 barrels.

The foregoing example illustrates the advantages that can be obtained by depressuring a heated oil bearing formation in accordance with my invention. It has previously been recognized that oil can be displaced by steam injection and then allowing the resulting condensate to flash into steam. However, to my knowledge no one has previously appreciated that a similar effect could be secured without the addition of extraneous steam or water merely by heating the connate water through combustion under conditions which keep such water in a liquid state, then reducing the pressure—preferably slowly—so that the water can flash in the pore spaces driving the oil therefrom.

It is to be specifically understood that the process of my invention is not necessarily limited to oils characteristic of those reservoirs in which forward combustion can be conducted by conventional methods. On the contrary, it is applicable to any reservoir in which the oil ranges in viscosity and gravity typical of tar, to crude oil having an API gravity of 40°.

For the purposes of this description, the expression "heavy oil" is intended to mean a crude having an API gravity less than 20°.

While it is mentioned herein that each producing well is shut in during the burning process as the combustion front is observed to reach a given well, the process of my invention is not limited to such a procedure but also contemplates placing sufficient back pressure on a producing well after the burning front has approached it to permit the average temperature of the water in the formation to reach or exceed 212° F. For the purpose of the present description and claims, reference to the shutting in of producing wells is intended to cover either of these conditions.

I claim:

1. In a method for the production of petroleum from an underground deposit thereof penetrated by an injection well and a producing well, the improvement which comprises introducing a fluid into said deposit at a pressure sufficient to lift the overburden on said deposit to create channels of increased permeability in said deposit and between said wells, thereafter establishing a burning zone in said deposit at the face of said injection well, next introducing an oxygen-containing gas into said injection well and then into said deposit at a pressure sufficient to maintain said channels of increased permeability while propagating said zone through said channels toward said producing well, continuing to introduce said gas until a temperature rise is observed at least in the immediate vicinity of said producing well, discontinuing the injection of said gas, shutting in said producing well to allow the resulting heat to diffuse out into said deposit until that portion thereof between said injection and producing wells and the connate water in said portion are at an average temperature in excess of about 200° F., thereafter opening said producing well whereby at least a part of said connate water in said portion is flashed into steam, and allowing the oil to flow from said producing well without the addition of further energy to said deposit.

2. The method of claim 1 wherein said deposit is an unconsolidated sand.

3. The method of claim 2 wherein the deposit is a tar sand.

4. The method of claim 2 wherein the production step is continued until the energy in said deposit is substantially spent and thereafter repeating the above cycle.

5. The method of claim 2 wherein the production step is continued until the energy in said deposit is substantially spent, and thereafter subjecting said deposit to a forward combustion step involving air and water injection, conducting said last mentioned combustion until heat breakthrough into said producing well is observed, discontinuing said air and water injection, shutting in said producing well and allowing the resulting heat to diffuse out into said deposit, thereafter opening said producing well and allowing the oil to flow therefrom without the addition of further energy to said deposit.

6. The method of claim 1 wherein a plurality of producing wells is employed.

7. In a method for the production of petroleum from an underground deposit thereof penetrated by an injection well and a producing well, the improvement comprising establishing a burning zone in said deposit at the face of said injection well, thereafter introducing air into said deposit via said injection well at a pressure sufficient to lift the overburden on said deposit to create channels of increased permeability therein and to simultaneously propagate said zone through said channels toward said producing well and continuing combustion under these conditions until the temperature increase is observed at least in the immediate vicinity of said producing well, thereafter discontinuing air injection under the aforesaid pressure conditions, shutting in said producing well to allow the resulting heat to diffuse through said deposit and particularly that portion thereof between said injection and producing wells thereby heating the connate water in said portion to an average temperature in excess of about 200° F., thereafter opening said producing well whereby at least a part of said connate water is flashed into steam, and allowing the oil to flow therefrom without the addition of further energy to said deposit.

8. In a method for the production of petroleum from an underground deposit thereof penetrated by an injection well and a plurality of producing wells, the improvement which comprises introducing a fluid into said deposit at a pressure sufficient to lift the overburden on said deposit to create channels of increased permeability in said deposit and between said injection and producing wells, thereafter establishing a burning zone in said deposit at the face of said injection wells, next introducing an oxygen-containing gas in the said injection well and then into said deposit at a pressure sufficient to maintain said channels of increased permeability while propagating said zone through said channels to said producing wells, continuing to introduce said gas in said deposit until said temperature increase is observed at least in the immediate vicinity of said producing wells where such temperature increase is observed, shutting in each producing well when a temperature increase is observed in at least the immediate vicinity of said each producing well, discontinuing the injection of said gas, allowing the resulting heat to diffuse out into said deposit until that portion thereof between said injection and producing wells and the connate water in said portion are at an average temperature in excess of about 200° F., thereafter opening said producing wells whereby at least a portion of said connate water in said portion is flashed into steam, and allowing the oil to flow from at least one of said produc-

ing wells without the addition of further energy to said deposit.

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